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Wi-Fi Real Time Location Systems

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WI-FI REAL TIME LOCATION SYSTEMS

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LIST OF ABBREVIATIONS

GPS: Global Positioning System

RF: Radio Frequency

RFID: Radio Frequency Identification

RSSI: Received Signal Strength Indicator

RTLS: Real Time Location System

GLOSSARY

Global Positioning System – A series of satellites in varying orbits around the Earth that provide timing signals to ground based receivers. When a receiver can receive these signals from at least three satellites it can identify, with a stated amount of accuracy, the receiver's location on the planet (Crimes, 2008).

Radio Frequency – An electromagnetic wave, with a frequency ranging from 3Hz to 300GHz, used in wireless communications(Mouser Electronics Inc, 2014).

RFID Tag/Badge - Act as beacons, transmitting location data to the appropriate software for mapping over scaled layouts. Features include over-the-air management, built-in motion sensors, and a rechargeable battery that can last up to five years (Ekahau, n.d. b).

Received signal strength indicator – The received signal strength in dBm from a Wi-Fi access point (IEEE, 2012).

Wi-Fi Access Point – Device containing 802.11 radios and bridges 802.11 wireless devices to a wired network or each other.

Wi-Fi Real Time Location System – An IEEE 802.11 based system that can locate and track a Wi-Fi enabled device based on varying received signal strength indicator (RSSI) values from visible access points("Wi-Fi ID: How," 2011).

ABSTRACT

Doll, Benjamin A. M.S., Purdue University, December 2014. Wi-Fi Real Time Location Systems. Major Professor: Anthony Smith.

This thesis objective was to determine the viability of utilizing an untrained Wi-Fi real time location system as a GPS alternative for indoor environments. Background research showed that GPS is rarely able to penetrate buildings to provide reliable location data. The benefit of having location information in a facility and how they might be used for disaster or emergency relief personnel and their resources motivated this research. A building was selected with a well-deployed Wi-Fi infrastructure and its untrained location feature was used to determine the distance between the specified test points and the system identified location. It was found that the average distance from the test point throughout the facility was 14.3 feet 80% of the time. This fell within the defined viable range and supported that an untrained Wi-Fi RTLS system could be a viable solution for GPS's lack of availability indoors.

CHAPTER 1. INTRODUCTION

This chapter begins with introducing the statement of the problem as well as the research question and its scope. This chapter finishes off the various assumptions, delimitations, and limitations related to the research.

1.1 Statement of the Problem

Over the last several decades there have been many large disasters such as the Mount Saint Helen eruption, September 11th, and Hurricane Katrina. To these disasters and many other situations, disaster emergency relief personnel, equipment, and supplies are deployed to aid the victims. Emergency relief personnel, especially first responders, may find themselves getting disoriented in familiar environments, which can make finding their way or others locating them quite challenging (Mapar, 2010). Being able to accurately locate these support personnel plays a vital role not only in their own safety but also in the lives of the victims of the disasters.

Identifying if it is feasible to utilize an already deployed Wi-Fi network, such as existing networks in housing facilities, to accurately locate and track emergency relief personnel, equipment, and supplies can provide the precious extra time needed to effectively handle the crisis at hand. Leaders of the various support groups would more easily be able to coordinate their resources, not just personnel but also equipment that may include medical supplies, vehicles, and communications equipment. Vital resources and equipment like these could be misplaced in the high-stress environment of a disaster or emergency situation. Losing track of them could have detrimental effects on the victims and support personnel.

Another point of view to consider is if these resources can be accurately located and tracked throughout a disaster/emergency environment then data could be used to better plan for similar future situations. Understanding where resources are located and how they are best allocated, and how they have been utilized in past situations can continue to increase the efficiency with which these events are planned, coordinated, and executed.

In indoor disaster and emergency scenarios it is important that personnel and resources not only be located and tracked but that it can be done accurately, to the degree that users have come to expect from systems such as GPS.

1.2 Research Question

Is an indoor Wi-Fi based real time location system (RTLS) a viable solution for location services as GPS based RTLS systems are for the outdoors?

1.3 Scope

This research is limited to determining the viability of utilizing a Wi-Fi real time location system to accurately locate and track wireless clients. GPS performance standards will be used to evaluate the accurateness of the Wi-Fi RTLS (Crimes, 2008).

There are two styles of Wi-Fi RTLS approaches: trained and untrained. As it would not be feasible for spontaneous deployment of a Wi-Fi RTLS system to be trained in potentially large indoor and potentially dangerous environments, only an untrained system will be considered for this research.

1.4 Significance

Being able to accurately locate, track, and assign resources and personnel in an emergency/disaster relief situation can play a large role in the success of the event. While positioning systems such as GPS may work well in open environments, they are not effective in urban or highly obstructed areas, or indoors (Mapar, 2010). Utilizing an already deployed Wi-Fi real time location system could allow emergency responders to quickly locate and track emergency relief resources and personnel as they arrive and through the duration of the event. However, it is important that the system be easily configurable and reasonably accurate in its ability to track and locate the resources. There appears to be little research into the viability of using an untrained Wi-Fi RTLS system to accurately perform this kind of spontaneous location tracking of resources, equipment, or personnel.

1.5 Assumptions

The following assumptions were taken into account for the study:

- The accuracy of the Wi-Fi real time location system utilized for the tests is a good representation of commonly used industry/enterprise solutions and can be generalized to other system manufacturers.

- The Wi-Fi real time location system, the Wi-Fi access points, and the tracked devices are all considered to be in full working condition during all portions of the study.
- The study area consists of a four-story building and is considered to accurately represent common RF obstruction.
- The Wi-Fi network and its associated access points are considered to be comparably deployed in the study.
- The overall environment in the study area, including but not limited to non-study participants and their devices, is not being considered during tests.

1.6 Delimitations

- The Wi-Fi location tests will not be tested on all available Wi-Fi access points, Wi-Fi real time location systems, or their associated tracking devices.
- Exact GPS coordinates of the tracked resource will not be gathered.
- The direction the devices being tracked are facing or their height from the ground at any given location during the study is not being considered, and the same reported location is to be expected when facing any direction or at any height unless otherwise noted.
- Variation of laptop and phone distance from specified test point are considered to be negligible and will not be considered in this study unless otherwise noted.

- Time between individual tests or travel time between test points is not being considered in this study.
- While Wi-Fi operates in two main frequencies, 2.4GHz and 5GHz, this distinction is not differentiated in this study. The laptop or phone can be connected on either frequency throughout the study.
- Wi-Fi real time location system supplementary location narrowing devices/appliances such as infrared sensors will not be tested during this study.
- While a hybrid GPS/Wi-Fi real time location system may be an ideal solution for a situation where the tracked resources could be both indoors and outdoors; these systems and their associated badges/tags will not be tested during this study.

1.7 Limitations

The following limitations were taken into account for the study:

- The boundaries of the study environment have been clearly defined and all tests will be conducted within its confines.
- This study will be conducted on tracked devices within the defined environment and both the calculated Wi-Fi real time location system's location and the "actual" location will be recorded, on which the viability and accuracy assessment will be performed.

- Accuracy of the Wi-Fi real time location system and its viability as a GPS alternative will be accounted for by the stated standard positioning service (SPS) signal in space (SIS) accuracy standard of ≤7.8m 95% Global Average User Range Error (URE) during Normal Operations over all Angles of Decent (AOD) expected when using GPS (Crimes, 2008). This will be the tolerance baseline for which the actual location compared to the Wi-Fi real time location systems reported location will be evaluated.

1.8 Chapter Summary

This chapter introduced the reason for the research that was conducted including the research questions and its scope. The various assumptions, delimitations, and limitations related to this research were stated providing a clear understanding of what the research pertains to in this thesis

.

CHAPTER 2. LITERATURE REVIEW

The focus of this review is to provide background on current Wi-Fi real-time location systems (RTLS) technology, the global positioning system (GPS), and bring to light any research that has been done on utilizing RTLS technologies as an alternative to GPS in a situation where it or one of its real-time tracking dependent technologies is not available. This review will also look into research and documentation where GPS has historically been unavailable to highlight situations where a Wi-Fi based RTLS solution could viably be used. This includes both locations with environmental limitations preventing GPS to function as well as external factors on the GPS system that may have caused inaccuracies, specific location outages, or even full system unavailability to end user devices. Additionally, the review will provide technical details on the expected accuracy GPS that will be used in the research as a baseline for determining whether a Wi-Fi based RTLS solution can accurately locate and track articles—not limited to resources, personnel, and so on. Finally, this review will provide a brief overview of situations that could benefit from a Wi-Fi RTLS solution if GPS was unavailable

2.1 Overview of real time location systems (RTLS)

The ability to locate and track resources in any situation can allow for insight into ways it can be improved (Zebra Technologies, 2013). Real time location systems can provide advantages in many areas including manufacturing, processing and distribution, as well as human asset tracking. Wi-Fi based RTLS solutions result from the need to actively monitor assets without being limited to the short ranges of traditional radio-frequency identification (RFID). Typically these passive RFID based tags must be within close range to a reader, usually no more than twenty meters or less. These systems are designed for a broader less dynamic view of tracked resources and are not ideal in time or location sensitive situations.

In contrast, RTLS solutions often utilize tags that have active radio/transmitters in them. These solutions are the quintessential homing beacon providing regular periodic location information. These solutions can have ranges of over a thousand meters depending on the implementation. Wi-Fi based RTLS solutions range is only limited by the wireless network. Often times these wireless networks provide overlapping signals from various radios allowing for the triangulation algorithms used by back-end software to compare the signals and judge its location as well as track its movements (Zebra Technologies, 2013).

2.2 Overview of traditional GPS

The inner workings of GPS are not often discussed as it has become very commonplace in today's technology. Officially known as Navstar Global Positioning

System, tracking systems, even ones that are considered RTLS systems, require two components. First they must have the necessary signaling provided by the GPS satellites as well as a method to transmit this data. GPS is one way and requires some type of location storage or communication. If it is using local storage then the device must be plugged into a computer to retrieve the data and by that definition is not RTLS. However, many devices have internal radios that use proprietary transmission methods, the cellular network, or even Wi-Fi (Sturza & Hills, 1995). GPS has its advantages. For example, it is globally available nearly everywhere outdoors, it is free to use, and is reasonably accurate within several meters. With those come its disadvantages. It is controlled and maintained by the United States Air Force, which means depending on someone else taking care of and ensuring the system is functional. Most of all, it is rarely available indoor (United States of American Department of Defense, 2008).

2.3 What makes GPS work?

GPS has three main segments: the space segment, the control segment and the user segment. The Navstar GPS system is owned by the United States Government, and the space and control segments are operated by the Air Force (US National Coordination Office for Space-Based Positioning, Navigation, 2013a).

2.3.1 Space Segment

The GPS signals are a one-way transmission of very precise timing signals. When a receiver is able to hear at least three of these timing signals, the receiver is able to determine its location (US National Coordination Office for Space-Based Positioning, Navigation, 2013b).

The Earth has a surface area of 198 million square miles, and GPS covers the majority of that area (Dutch, 2009). The space segment facilitates that coverage with a constellation consisting of over 30 satellites (US National Coordination Office for Space-Based Positioning, Navigation, 2013c). The Air Force's goal is for no less than 24 of the GPS satellites in the space segment to be available at any given time, 95% of the time. These satellites orbit around the Earth at just over 20,000 kilometers, an altitude classification known as medium Earth orbit (MEO). There are 24 unique orbits providing nearly any point on Earth visibility of at least four satellites. These orbits can be seen below in figure 2.1 (US National Coordination Office for Space-Based Positioning, Navigation, 2013c).

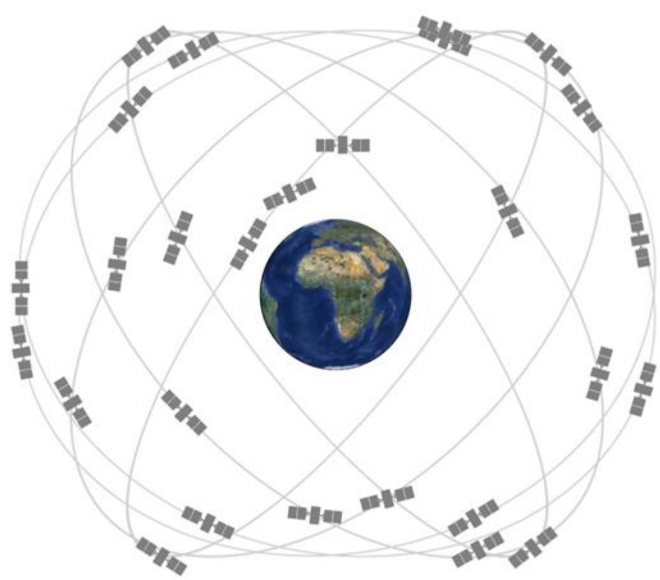

Figure 2.1 - Expandable 24-Slot satellite constellation

2.3.2 Control Segment

The second segment of GPS is the control segment. It functions to control the GPS constellation and ensure that it is functioning properly. As shown in figure 2.2, the various ground antennas and control stations that communicate with the GPS can be seen (US National Coordination Office for Space-Based Positioning, Navigation, 2013d).

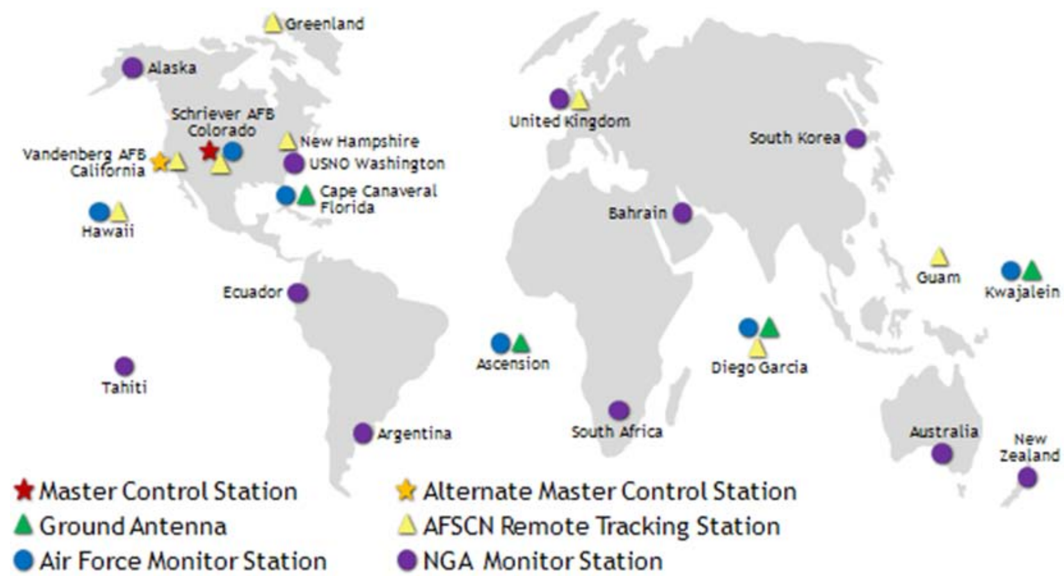

Figure 2.2 - GPS Control Segment

There are two control stations, a master and alternate that can be seen in figure 2.2, both in the United States (US National Coordination Office for Space-Based Positioning, Navigation, 2013d). The remaining locations are the various antennas, tracking, and monitoring stations. This system allows for the GPS constellation to be constantly monitored and updated as needed. This includes bringing the various satellites online and offline for maintenance as well as realigning orbit to maintain full system functionality (US National Coordination Office for Space-Based Positioning, Navigation, 2013d).

2.3.3 User Segment

The user segment is where all the pieces come together and the system is put to its many uses. Currently GPS systems can be found in numerous applications including agriculture, aviation, environment, marine, public safety and disaster. The National Coordination Office for Space-Based Positioning, Navigation, and Timing reiterates this saying, "New uses of GPS are invented every day and are limited only by the human imagination" (US National Coordination Office for Space-Based Positioning, Navigation, para. 5)." All three segments come together and form the location piece of GPS based real time location systems (RTLS). Add in the actual communication to relay that data in real time, and that is a modern day GPS RTLS based system.

2.4 But GPS is everywhere …

GPS does have near global coverage, however the signal is not necessarily available everywhere. It works best in an environment with clear line of sight to the sky (Fredrick, 2013). Remember that GPS is just another radio frequency, in this case, the ultra-high frequency (UHF): 1575.42 MHz. This signal, like any other, can be blocked or attenuated to the point it cannot be used. Users who generally see this are ones with cell phones that have GPS enabled. Oftentimes users of GPS devices will be alerted that the GPS signal was lost upon entering a building, driving under a bridge, or entering a tunnel. For the signals that can penetrate to indoor environments there are usually more opportunities for interference, such as UHF-based TV antennas (Fredrick, 2013). Additionally, the environment can impede GPS signals, for example heavily urban environments with tall buildings and even more densely forested areas. Lastly, there are factors that cannot be accounted for that affect GPS, such as solar flares. Three solar flares, two in 2006 and one in 2008 were seen to affect GPS accuracy and availability (Afraimovich, Demyanov, Gavrilyuk, Ishin, & Smolkov, 2009).

2.5 GPS real time location systems (RTLS)

RTLS solutions that rely solely on GPS to locate and track something suffer in situations where the GPS signal is unavailable. Additionally these systems require a method to share its data in near real time to provide the tracking component of a GPS RTLS. These can be any varying types of communication modes: cellular, Wi-Fi, proprietary radio. It is important to consider the effect on the system's ability to locate and track resources if a portion of the system were to fail.

2.6 Availability of Wi-Fi

A solution that can utilize already-deployed Wi-Fi networks to help locate resources or personnel can provide the necessary inside and even outside coverage for a specific application. For example, the Purdue University campus in West Lafayette has over 5,500 access points deployed on its campus. A Wi-Fi resource that is readily available, or one that can easily be deployed, provides a lot more of the control to the end user of the real time location system (RTLS) as opposed to being dependent on only GPS, especially in indoor situations where GPS is known to function minimally, if at all.

Manufacturers of RTLS systems have combined the functionality of both systems and incorporated both GPS and Wi-Fi in a device to provide the location data. Systems such as this now utilize the availability of GPS outdoors and transition to Wi-Fi when out of range of GPS, providing seamless location and tracking data of assets. Hybrid solutions such as these are growing; Identec Solutions has designed two systems with hybrid location functionality to track shipping containers as cranes move them from place to place (Identec SolutIons, n.d.).

2.7 Location Accuracy

GPS has been fully functional for nearly two decades and has been highly utilized to provide location services (U.S. Air Force, 2010). With that the system has become trusted in its accuracy and will serve as the baseline of accuracy for the research being done. The accuracy of GPS is given as less than or equal to "7.8 m 95% Global Average URE during Normal Operations over all AODs" by the Department of Defense (United States of American Department of Defense, 2008). Additionally, the Department of Defense provides the standard annual average accuracy of GPS at less than or equal to "30 m 99.94% Global Average URE during Normal Operations"; taking into account typical outages experienced by a quality fully functional radio (United States of American Department of Defense, 2008, p. 22). The research being done on Wi-Fi based RTLS systems will be directly compared in terms of accuracy to GPS's best and worst case scenarios to provide insight into its overall ability to accurately locate end users. Vendors such as Ekahau, leaders in the Wi-Fi RTLS market, have products that they claim can achieve an average accuracy within 15 meters (Ekahau, n.d. a).

2.8 Overview of Research

The research being done will be closely looking into the viability of using Wi-Fi based real time location systems to locate and track resources or personnel and comparing its accuracy against that of the expected tolerances in accuracy from GPS systems. This research will be beneficial in research where GPS is not available everywhere. An example is Purdue University. Purdue is a large campus that is very much outdoors and indoors. Having a Wi-Fi based RTLS system, maybe even a hybrid GPS system, would allow for the locating and tracking of Purdue personnel (e.g., Grounds, Fire, Police) even students throughout the entire campus. Purdue Air Link (PAL) 2.0 and 3.0 cover the majority of campus and are constantly growing. Being able to utilize this already deployed Wi-Fi environment for any number of Purdue resources could benefit its students, faculty, and staff. While the system can actively monitor movement imagine being able to review traffic patterns of the 40,000 students on campus. All the phones, tablets, and laptops connected to PAL can be tracked and analyzed to make campus more efficient in many cases: disaster situations, sports and athletic events.

While existing Wi-Fi networks are useful, there are also opportunities to utilize Wi-Fi RTLS systems in disaster or emergency relief scenarios. First responders could deploy an affordable network that would allow for the accurate tracking of resources and personnel on site. These could be challenging environments for GPS or traditional communication systems, but Wi-Fi provides a way to service emergency responders and allow them and their resources to be accounted for (Mapar, 2010). While the specific uses of a system such as this is out of scope, it is important to realize the impact a dynamic, easily deployed or adapted wireless network could have on tracking any resource.

CHAPTER 3. METHODOLOGY

This research focused on identifying the viability of using a Wi-Fi real time location system to locate and track resources with reasonable accuracy. "Reasonable" accuracy was determined using Global Positioning System (GPS) as a baseline. The background of this research was based in situations where GPS may not be available. This may have been because the signal was being blocked by structures around a user or that they were in a structure the signals cannot penetrate. Another possibility is that in some form of malfunction or malicious intent the GPS system would be unavailable. The need to locate and track resources in a situation like this may be even higher. Being able to utilize existing Wi-Fi networks or being able to rapidly deploy a network to provide those services may be quite beneficial.

3.1 Hypothesis

This research study will involve the following hypothesis:

H_0: A Wi-Fi RTLS system is not a viable alternative to GPS; in its ability to accurately locate and track resources should GPS be unavailable.

H_α: A Wi-Fi RTLS system is a viable alternative to GPS; in its ability to accurately locate and track resources should GPS be unavailable

3.2 Study Environment

The study took place utilizing Crosswalk Commons wireless network and the controller's locations services as the Wi-Fi portion and RTLS system. This building represented a typical RF environment. This network provided a good representation of a well-designed and implemented enterprise network.

3.3 Permissions

Crosswalk Commons was contacted and gave approval to interface with the Wireless network at the facility (CW-Wireless) to use as the Wi-Fi network and RTLS portion of this research. Other than granting access to the controller interface, giving access to the location services functionality, no special configuration of the existing Wi-Fi deployment was necessary.

3.4 Procedures

Tests were performed against devices moving throughout the Wi-Fi RTLS coverage area. The coverage area included testing on each of the four floors of the Crosswalk Commons building. This study, since it represents an already deployed enterprise Wi-Fi network being used for RTLS, may provide insight for applications that were discussed in earlier sections. It was necessary to properly identify what is considered "true" or "actual" locations in the test area. Blueprints of each floor of the building were provided by Crosswalk Commons and were used to properly track both the measured location and RTLS systems calculated location. It was necessary to ensure a consistent scale of the blueprints to ensure accurate representation of the "true" or "actual" location. The

Wi-Fi access point's locations were also provided by Crosswalk Commons and plotted for each floor on the maps. Upon overview of the blueprints, test points were identified throughout the building. Common areas and hallways were broken down into smaller regions where test points were approximately 20 feet apart. This represented clear break points throughout the building providing enough data to put the surrounding points within easy view of the others, allowing for consistent test locations. The hallways, common areas, and non-apartment unit test point locations can be seen in the Appendix.

In addition to the hallways and common areas, 26 of Crosswalk Commons 32 units were readily accessible for testing. Each unit type was broken down into smaller regions similar to the hallways and common areas. The breakdown consisted of a test point in each unit's kitchen, living, bath, and bed rooms. The smallest unit consisted of four test points while the largest unit consisted of eight. Crosswalk Commons units can be summarized into three main styles; 1 bedroom, 2 bedroom, and 3 bedroom units. These units and the testing points for them can be seen in figures 3.1 -3.3 below (Southwest Contract, 2013).

Figure 3.1 – Crosswalk Commons Single Bedroom floor plan test locations

Figure 3.2 – Crosswalk Commons Two Bedroom floor plan test locations

Figure 3.3 – Crosswalk Commons Four Bedroom floor plan test locations

After defining the test points through the Crosswalk Commons facility data gathering began. In each of the accessible units, hallways, common areas, and office locations a series of three location tests were performed using the Wi-Fi system's location services. This process consisted of a triggered station locating process that upon completion presents all identified stations at their system observed location. The location system interface can be seen in figure 3.4.

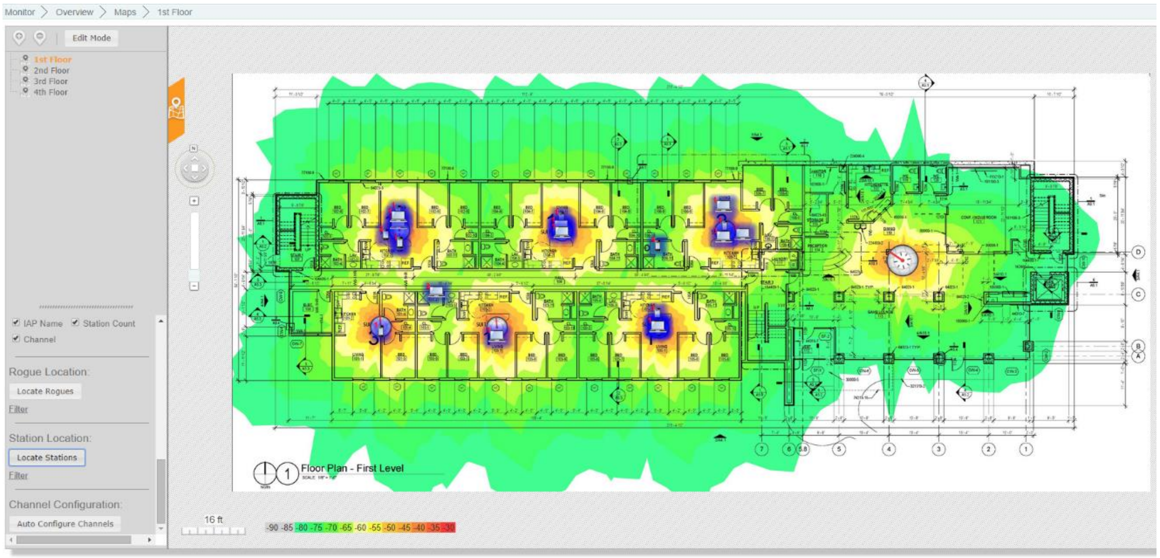

Figure 3.4 – Location System Interface

Once the system plotted the location of the stations, the map was zoomed in for the best view of both the laptop and phone stations in the test. The map was then captured using the windows snip tool, and both the laptop and phone were marked with a white circle for identification and measurement after data collection. Each test was performed and recorded in this manner. Each image file was saved with a naming schema of Room-Location-Test#, e.g. 202-4-2. An example of the screen capture can be seen in figure 3.5.

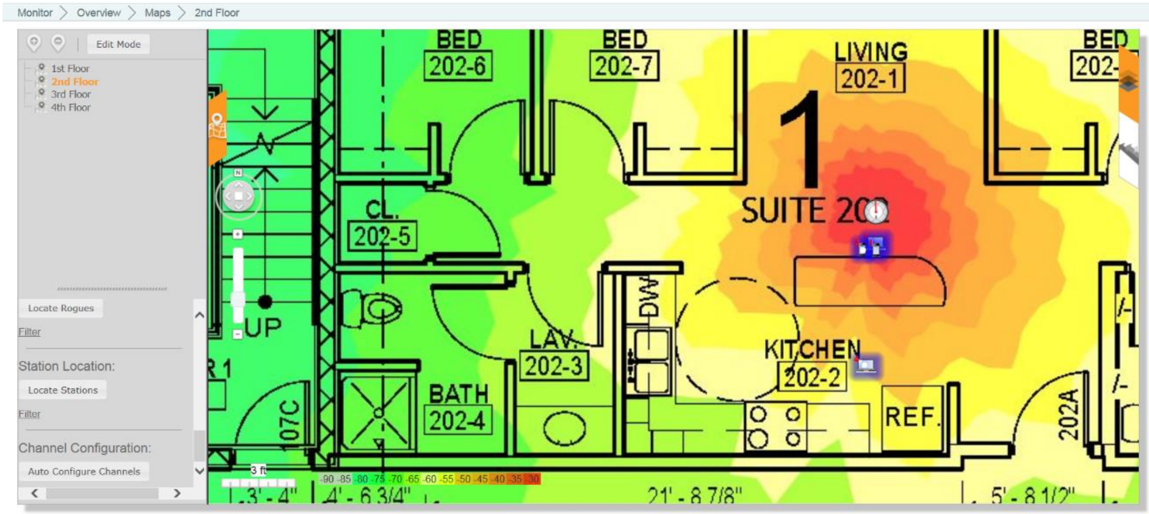

Figure 3.5 – Location Plotted Screenshot Sample

Following the completion of the data collection the images were translated into measurement data. Each image contains the two marked devices, one laptop and one phone, and a scale in the bottom right corner. Using a graphics editor the test location was laid over top the image and the distance was measured between that point and the center of the laptop and phone image. When either the laptop, phone, or both were not located on the map following the locating process it was indicated with NOF – Not on Floor. An example of the measurement process and results can be seen outlined in red in figure 3.6.

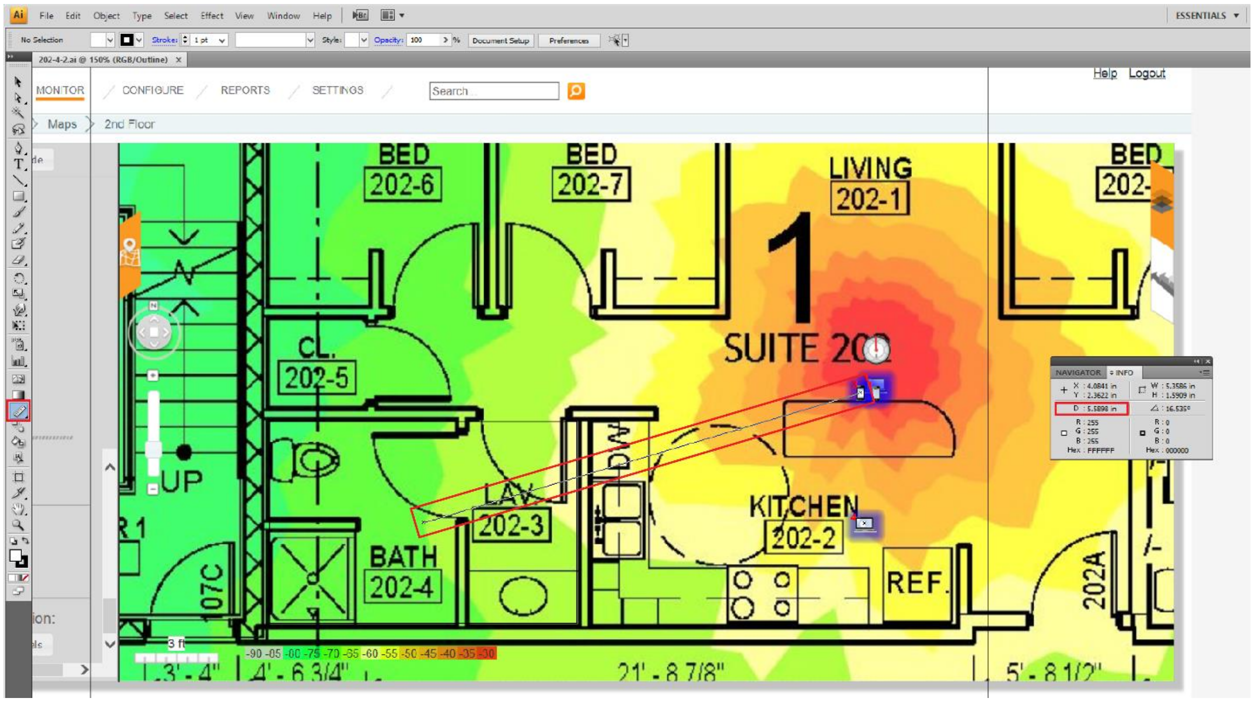

Figure 3.6 – Location Measurement Procedure Example

Once the test locations representing the “actual” location have been marked and the location of the laptop and phone plotted the relationship will be evaluated. This will include but is not limited to determining if the variance in the “true” or “actual” location from the RTLS system’s reported location is within the accepted accuracy range as given by the previously stated GPS standard. With GPS signals being attenuated anywhere from 10 to 100 times their original power when inside buildings, “viable” in this study will be defined as having at least 80% of the test locations within the 7.8m GPS standard (Nirjon et al., 2014). This would indicate that at least four out of five readings met the standards indicated. Considering that GPS is rarely available in and indoor environment such as Crosswalk Commons this was determined to be reasonable when evaluating an untrained Wi-Fi RTLS systems accuracy.

3.5 Summary

This section explained the methodology the research question was evaluated with. It gives an introduction to the actual testing process followed by the hypothesis clearly defining how the viability in regards to accuracy will be determined. This methodology provided the outline and process that provided consistent useful data collection.

CHAPTER 4. RESULTS AND ANALYSIS

The data collected during this research study consisted of individual data for both the laptop and phone utilized during testing. These two devices were tested in each of the 246 test points in three iterations of the defined methodology for the study providing a total of 1476 points used for analysis. This chapter focuses on the arrangement and presentation of the collected data.

Following the data collection phase, when transposing the graphics into distance number data, additional metadata was added to further define and highlight how distances in buildings can be quite different than those outdoors. Whenever a data point was outside the apartment unit or measurement area, such as in hallways, this was indicated by appending NIA – Not in Area. This allowed for further analysis on the indoor distances and provided perspective on the how indoor distance differences, while often smaller, can still account for serious accuracy issues within the test environment.

4.1 Measurement Comparison against GPS Standard

The test points provide insight into the common locations throughout the Crosswalk Commons facility. These 246 testing points were each tested in three iterations using the described methodology for both the laptop and phone used in the study. This provided three measurements for each test location. Each of these values were directly compared against these two GPS standards:

- "≤ 7.8 m 95% Global Average URE during Normal Operations over all AODs" (United States of American Department of Defense, 2008)
- "≤ 30 m 99.94% Global Average URE during Normal Operations" (United States of American Department of Defense, 2008)

The results of this direct comparison for both the laptop and phone can be seen in figure 4.1.

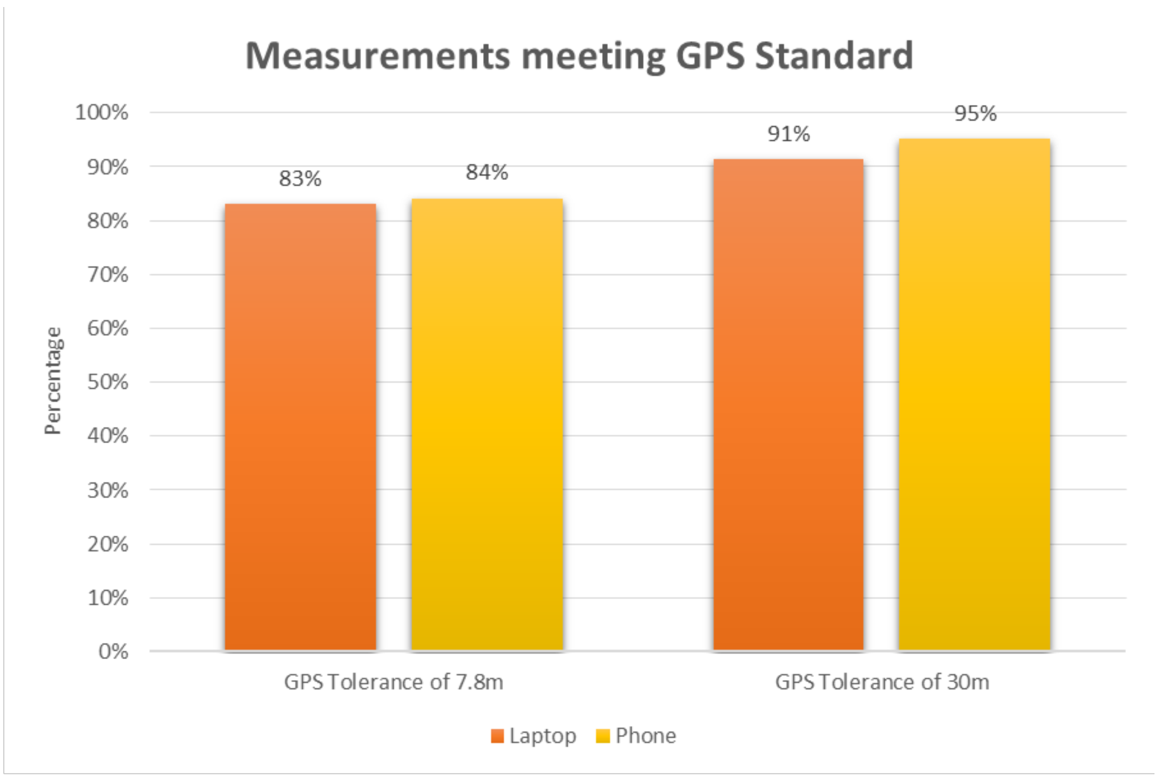

Figure 4.1 – Percentage of data points meeting GPS Tolerance Standard

4.1.1 Hallway/Common Area and Apartment Unit Breakdown

The hallway/common areas were grouped and compared against the GPS Standards individually as can be seen in figure 4.2.

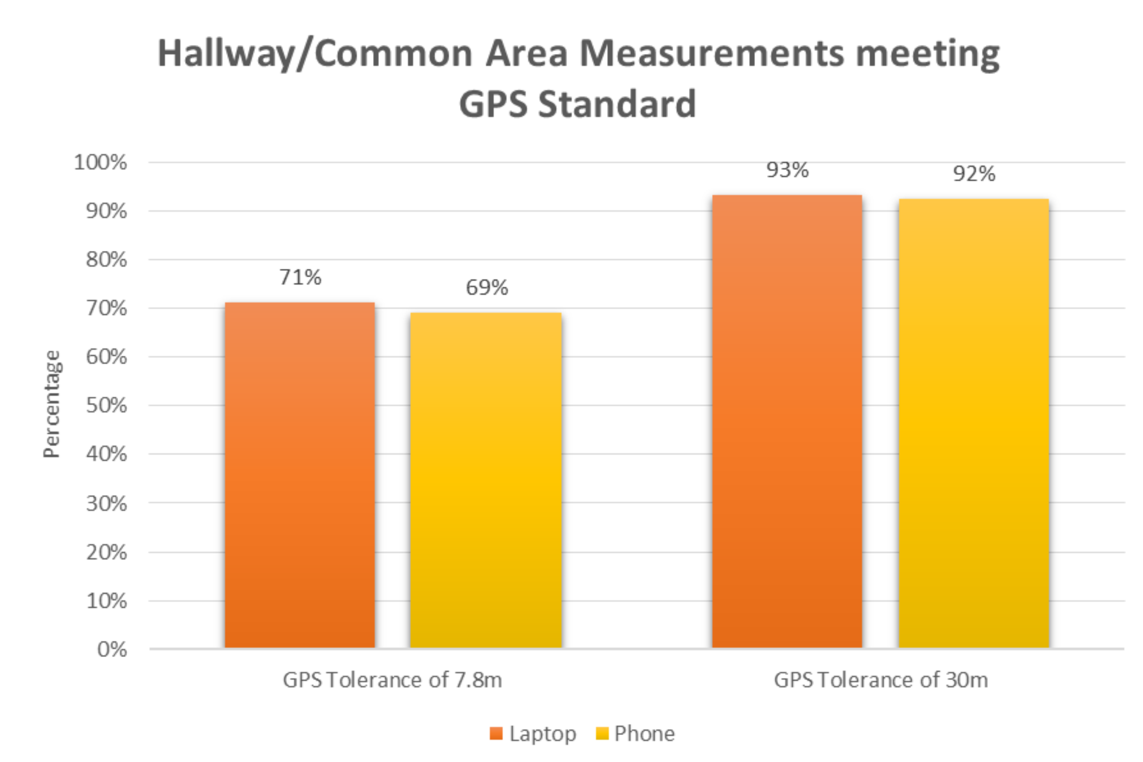

Figure 4.2– Percentage Hallway/Common Area data points meeting GPS Tolerance Standard

The apartments units were grouped and compared against the GPS Standards individually as can be seen in figure 4.3.

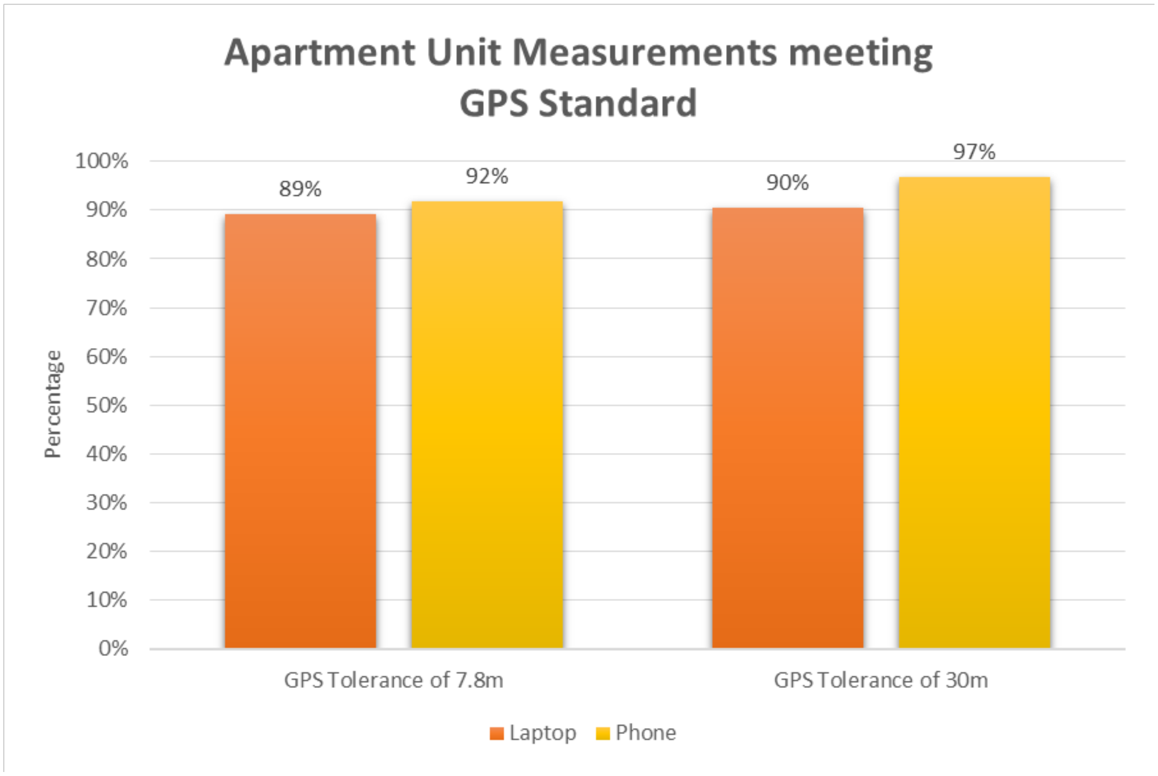

Figure 4.3– Percentage of Apartment Unit data points meeting GPS Tolerance Standard

4.2 Adjusted Measurements

Once data was gathered it was converted into distance measurements that could be directly compared against the GPS standards the study was designed around. Additional metadata was noted with the measurements to be considered during the comparison of the untrained Wi-Fi RTLS systems accuracy against the GPS Standards outlined in the study.

4.2.1 NIA – Not in Area

Test points defined as NIA – Not in Area and NOF – Not on Floor provide important insight into the ability to accurately track assets and resources in an environment. Throughout the testing these notated values were commonplace for both the laptop and phone measurements. Nearly a third of the data was identified as being NIA. A breakdown of this can be seen below in figure 4.4

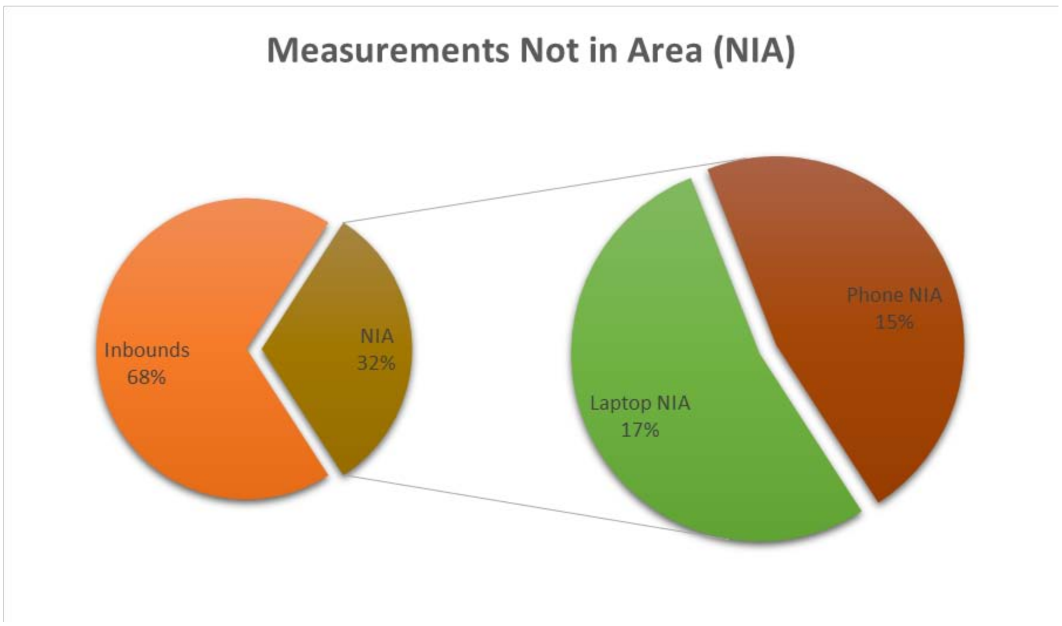

Figure 4.4– Percentage of data points identified as NIA

4.2.2 NOF – Not on Floor

Of the test points identified as NIA – Not in Area, an additional dimension can be seen when identifying the test points that were also NOF – Not on Floor. This is important as the system was not able to locate either the laptop or phone at that test point iteration. The total NOF test points only account for approximately 7% of the total readings but when compared to the NIA points, as seen in figure 4.5, their significance cannot be discounted and will be noted when considering the system's comparability to GPS.

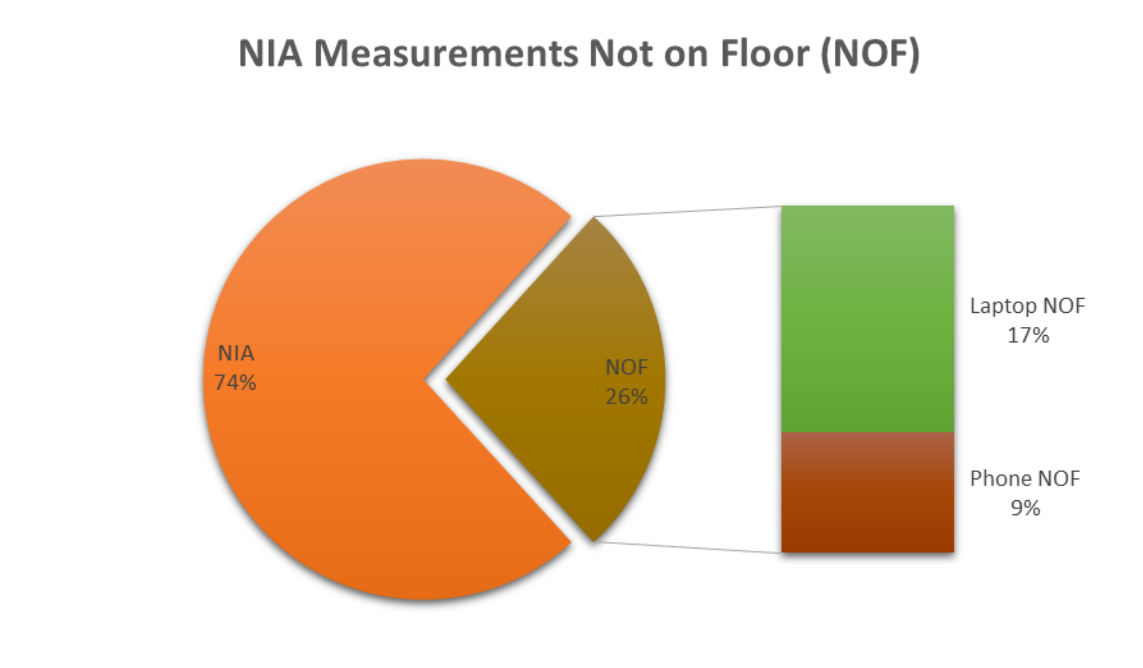

Figure 4.5– Percentage of data points identified as NOF

4.2.3 Adjusted Measurements Comparison against GPS Standard

This additional metadata was taken into account and used to adjust the requirements to meet the GPS standard. This adjustment provides a compensation for the severity of an incorrect reading within the facility. The same data was taken and test points that met the GPS standards and also indicated as indicated as NIA – Not in Area were not considered a match. The resulting percentage of test points can be seen in figure 4.6 below.

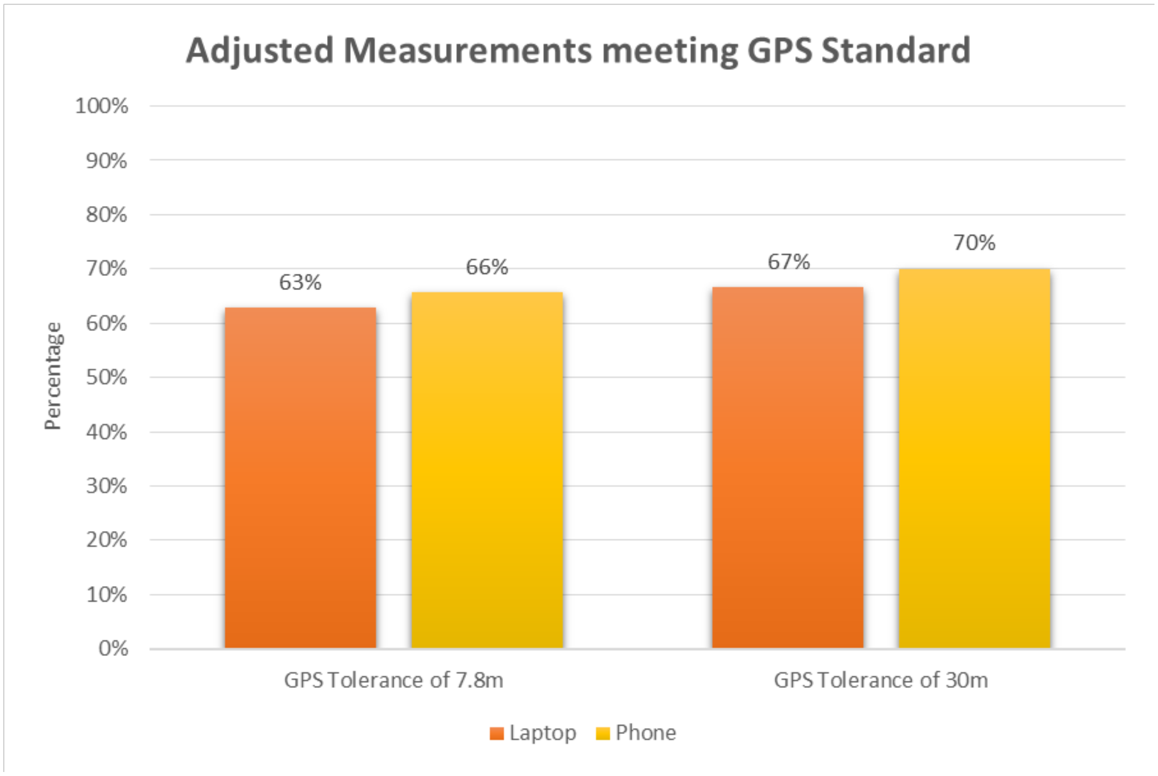

Figure 4.6– Adjusted Percentage of data points meeting GPS Tolerance Standard

4.2.3.1 Adjusted Hall Measurement Breakdown

Similarly, the test points were adjusted for both the hallway/common area and apartment unit groupings providing the adjusted comparison against the GPS standard. The hallway/common areas were grouped and compared against the GPS Standards individually as can be seen in figure 4.7.

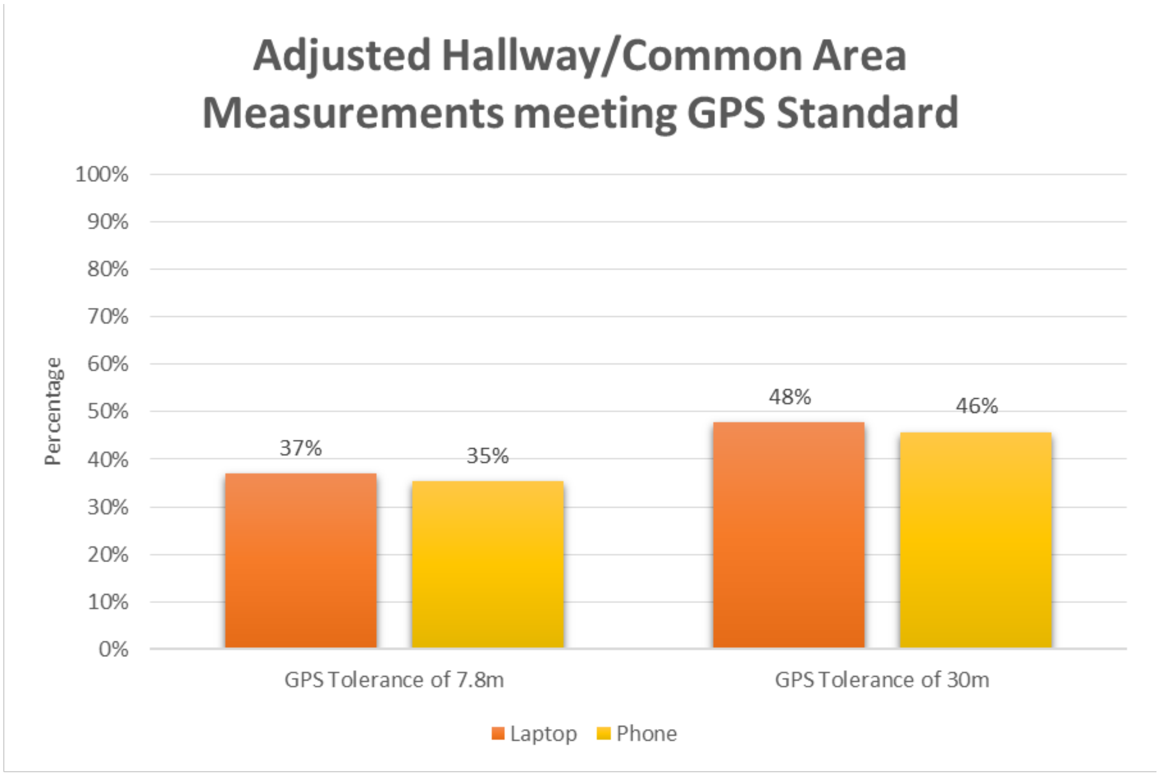

Figure 4.7– Adjusted Percentage Hallway/Common Area data points meeting GPS Tolerance Standard

4.2.3.2 Adjusted Room Measurement Breakdown

The apartments units were grouped and compared against the GPS Standards individually as can be seen in figure 4.8.

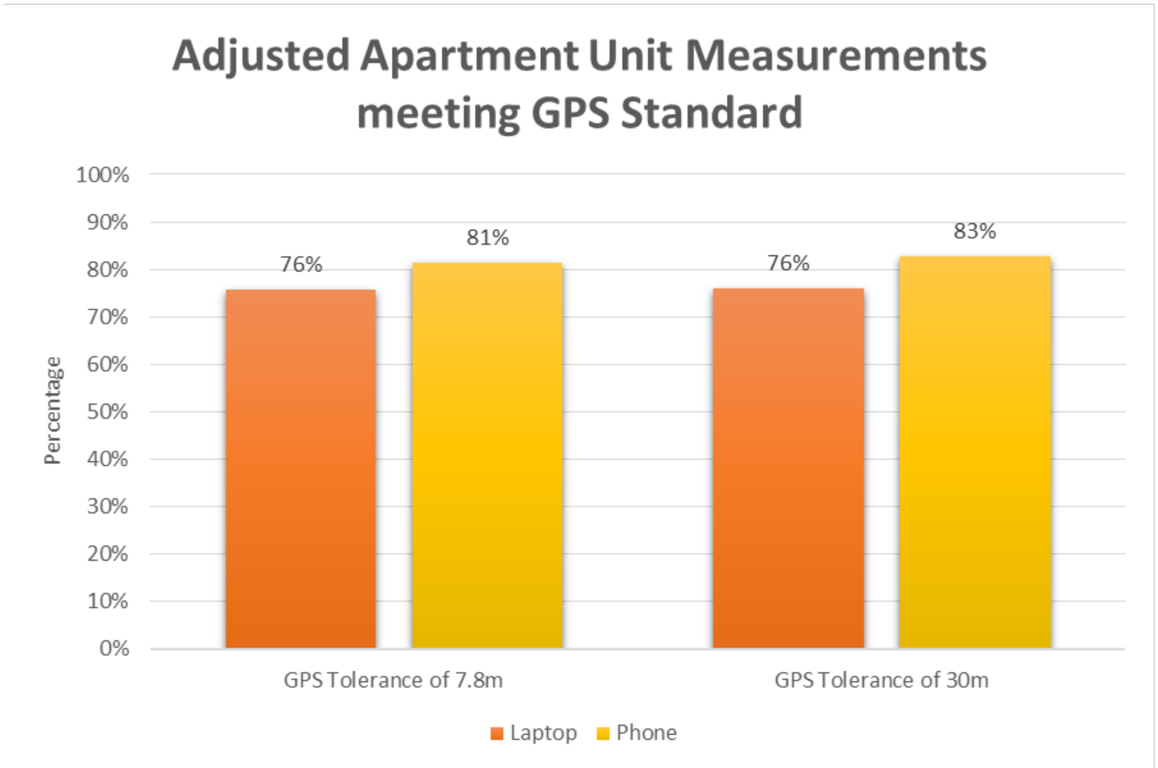

Figure 4.8– Adjusted Percentage of Apartment Unit data points meeting GPS Tolerance Standard

4.3 Measurement Breakdown

While the test environment is assumed to be a good representation of typical building construction, there are internal features unique to the building that account for varying RF propagation and in turn degrees of accuracy. Each building has unique features and for this reason readings were not excluded when calculating the average accuracy of readings for the laptop and phone. Ultimately these average values will be used to determine the systems viability against the averages provided in the GPS standard. The averages across each iteration of tests for each devices and the aggregate average can be seen below in table 4.1.

Table 4.1 – Average distance values in feet from test location

	Test-1	Test-2	Test-3	TOTAL
AVG-Laptop	14.5	13.8	12.5	13.6
AVG-Phone	16.6	14.2	13.9	14.9
AVG-Aggregate	15.6	14.0	13.2	14.3

4.3.1 Hallway/Common Areas Measurement Breakdown

Over each test it can be seen that the average distance is well within the bounds of the GPS Standard, providing a total average across the three tests for each device more than ten feet below the GPS Standards tolerance. The tests resulted in an average accuracy for both devices being located within the GPS standard of less than or equal to a 7.8m average 95% of the time (United States of American Department of Defense, 2008).

Breaking those results down further, the hallway/common areas were grouped and averaged for each device in table 4.2.

Table 4.2 – Average Hallway/Common Areas distance values in feet from test location

	Test-1	Test-2	Test-3	TOTAL
AVG-Laptop	19.2	19.1	15.8	18.1
AVG-Phone	20.8	18.8	17.8	19.1
AVG-Aggregate	20.0	19.0	16.8	18.6

Table 4.2 steps into the hallway\common areas grouping of data and shows the average accuracy for both the laptop and phone across all three iterations of testing. This shows that the hallways despite their higher average are still within the GPS Standard consistently by more than five feet.

4.3.2 Apartment Unit Measurement Breakdown

The apartments units were also grouped and compared against the GPS Standards individually as can be seen in figure 4.3

Table 4.3 – Average Apartment Unit distance values in feet from test location

	Test-1	Test-2	Test-3	TOTAL
AVG-Laptop	11.9	11.1	10.8	11.2
AVG-Phone	14.5	12.0	12.0	12.8
AVG-Aggregate	13.3	11.6	11.4	12.1

Table 4.3 provides the same type of data discussed with the hallway/common area group. The average across the three iterations of the test as well as the total average have dropped considerably and show that the system is on average especially accurate within the apartment units. The data points were found to on average be more than twice as accurate as the GPS standard.

4.4 Summary

The data collected and presented here provides insight into the viability and accuracy of a Wi-Fi RTLS system. The laptop and phone distance measurements do vary from each other however, tend to perform similarly and consistently throughout the study. The data provided here shows an average measured distance accuracy well within the defined GPS standards over the iterations at each data point. While the data does provide overview of the values directly compared to the standard, the standard is given as an average and the average will be used to state the results.

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

This study provided results that provide a reasonable level of accuracy that might be unexpected from an untrained Wi-Fi RTLS system. The research was focused on a well-designed Wi-Fi network being tested for the accuracy at which it could locate and track assets. While considerable research exists regarding the accuracy of various Wi-Fi RTLS systems, many of them require training, and little has been done to directly compare the systems directly to the widely accepted accuracy of GPS.

Collectively, GPS has numerous variations and several extensions to the systems utilizing terrestrial based correction mechanisms. The civilian SIS GPS accuracy standards used were selected from the Global Positioning System Standard Positioning Service Performance Standard 4th Edition published in September of 2008. These standards were directly compared to the distances measured between the test point and RTLS system's plotted locations of the laptop and phone in the test.

Looking overall at the results from the study, both the laptop and phone's average plotted distance from the test points were well within the 7.8 meter standard—often times by ten feet or more. Looking at each of the identified groups the hallway/common area group was found to be on average less accurate but still within the GPS tolerance by at least five feet. The apartment units group was identified as being on average more accurate than the hallway group and within the GPS tolerance by seventeen feet, something suspected to be related to access point placement but outside the scope of this research.

This study was intended to provide insight into the accuracy of an untrained Wi-Fi RTLS system and how it compares to the defined GPS standards. The collected data from the test points were evaluated against the standard and provided comparison of how often the data was found to meet the 7.8m standard and additionally the average year standard of 30m. At least 80% of the individual data points were found to be within the defined 7.8m standard. However, the standard provides an average of its data points and therefore requires the systems viability, in regards to accuracy, to be determined by the collected data's average.

Changing perspective the individual data points were viewed again looking at the data from the hallway/common area and apartment unit groups. It was found that the apartment unit readings where significantly more accurate by approximately 20% in regards to the 7.8m standard. The much higher tolerance of the 30m standard did not change any more than 5%. While this was not utilized to determine the system's viability as a GPS alternative it is important to consider when looking at the individual test locations. Knowing the test point are in an apartment unit give a higher accuracy profile based on these results.

Many of the readings taken when translated were identified as not being within the same area as the test point. This was identified by two indicators; NIA – Not in Area and NOF – Not on Floor. This metadata provided insight into the accuracy of the system as a whole, and accounts for the severity of being in the wrong room. Considering the desire to utilize systems such as these for potential disaster or emergency situations this was a vital metric in considering the true accuracy of the Wi-Fi RTLS system.

Of the 1400+ data points 32% were identified as being outside the immediate testing area. This consisted of both the laptop and phone readings and included the unattainable NOF – Not on Floor measurements. Nearly 1/3 of the collected data points were found to fall outside of the testing area. Of those readings, over 20% of them were found to be labeled as NOF, meaning the system was unable to plot them on the current floors map. While this data was not directly used to determine the system’s viability as an indoor GPS alternative, it provides necessary insight that could be expanded on in future research. For example, two feet away from the actual test point could be in the same room or the next apartment unit and could be disastrous for emergency personnel when lives are involved.

This research was done to answer the research question, determining if the system is a viable alternative to GPS RTLS systems for the indoors. Looking critically at the standard and the compiled data, the accuracy of the Wi-Fi RTLS system was found to be a viable alternative to GPS as it averaged across all three tests at each location well within the bounds of GPS’s 7.8m standard at least 80% of the time. This results in a system that is able to perform and offer reasonable data to support its ability to accurately locate and track assets with an untrained Wi-Fi RTLS system.

5.1 Future Work

Future work to be considered in this area is specifically how various commonplace Wi-Fi devices affect the systems overall accuracy. This is essential research as there are thousands of different Wi-Fi enabled devices, and while they are all designed around a standard, each can perform uniquely. Having a solid understanding of the effect on accuracy of tracking user say via tablet versus a phone or laptop is important.

Additionally performing this research across other building types would be beneficial. Having an accuracy gauge of other building-types that include concrete or brick interiors would provide a profile that could be used in conjunction with the readings to determine logical accuracy within the facility.

The research done here, while not directly tied to emergency and disaster relief situations, could be expanded upon to look closer at the utilization of an untrained Wi-Fi RTLS system for those purposes. There is value to be found in more accurately locating and tracking resources and personnel.

In conclusion, as more and more deployments of Wi-Fi are seen outdoors it could be viable to compare Wi-Fi and GPS locationing against each other in real-time. This would provide the potential for accuracy better than either system could provide independently. As technology continues to develop and expand there will be countless opportunities to build on this foundation and provide insight into these systems ability to provide tracking data that previously had not been considered.

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APPENDIX

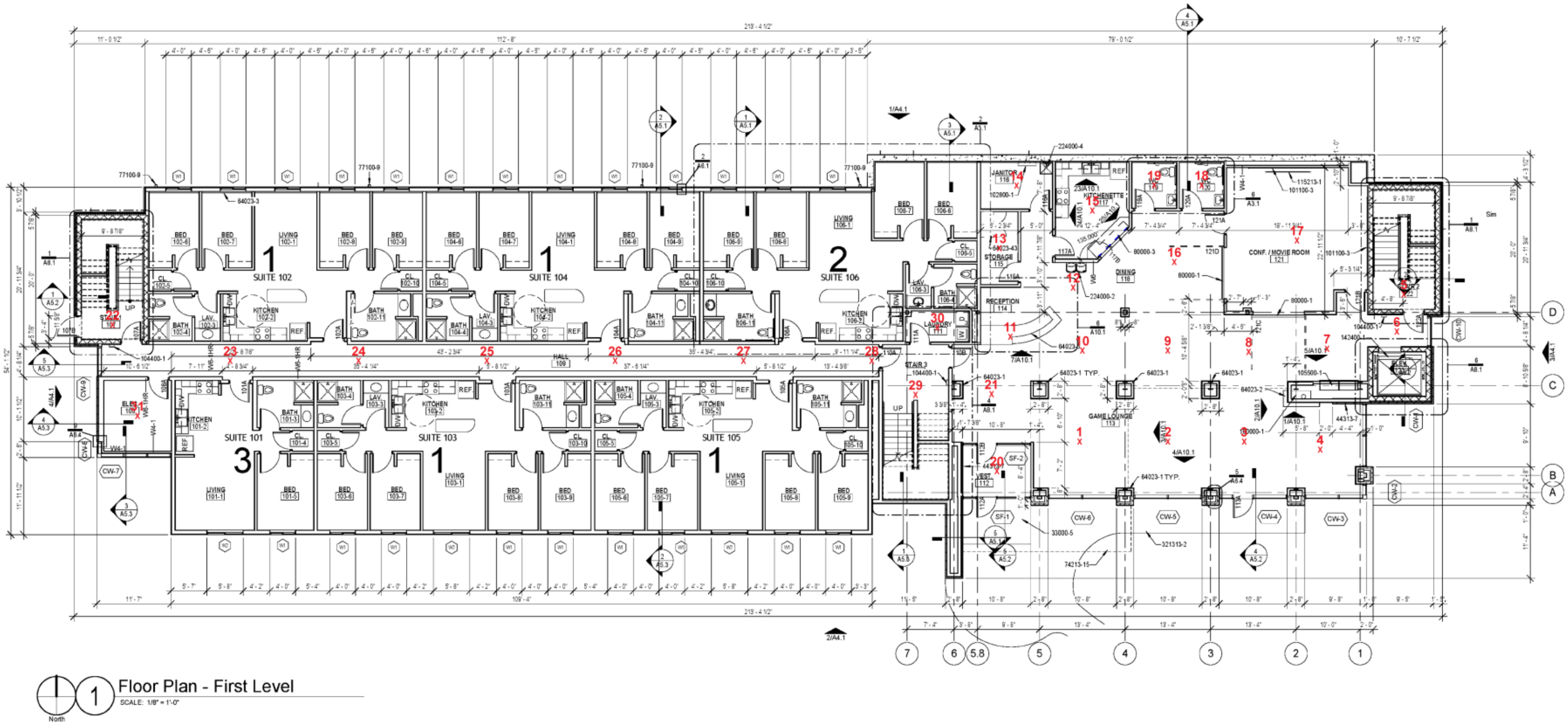

Figure A.1– 1st Floor Test Locations

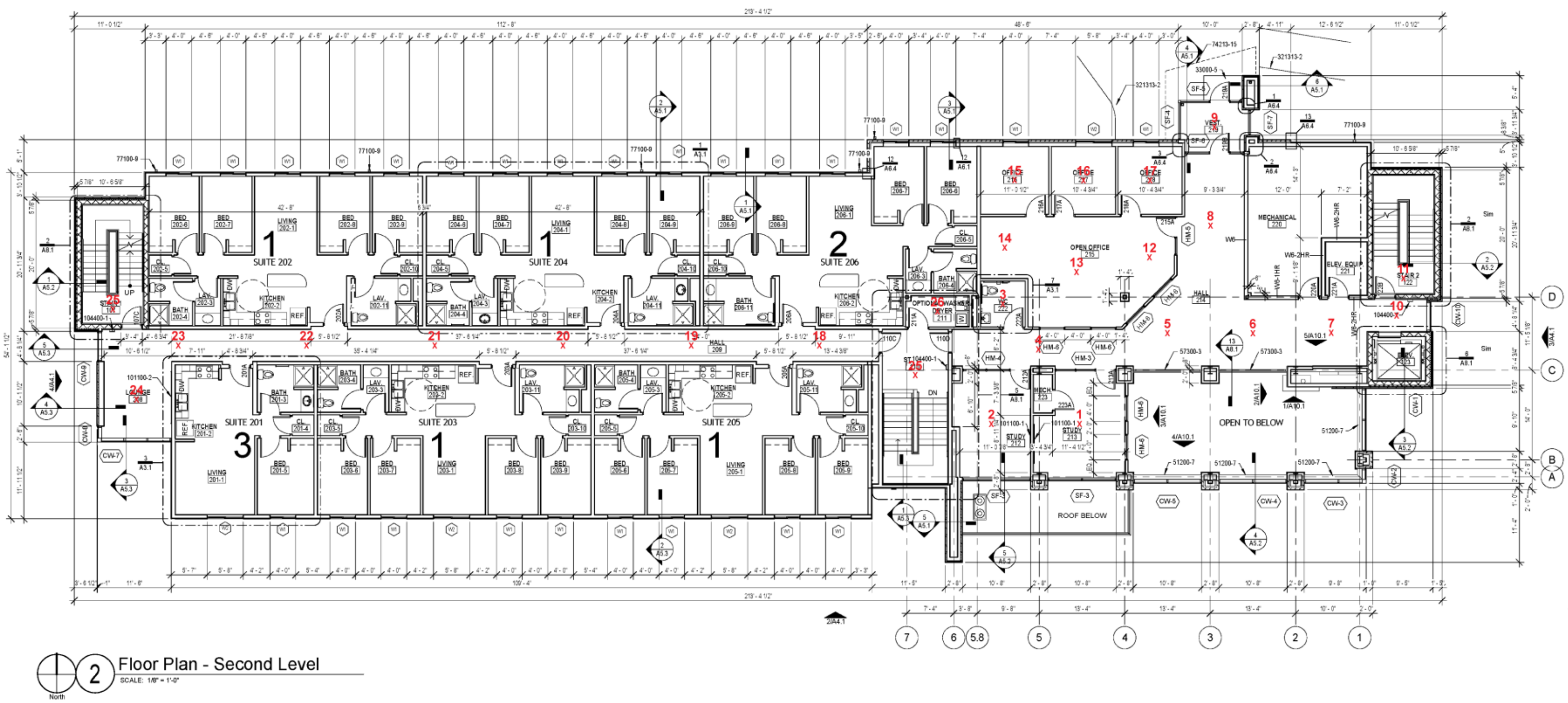

Figure A.2– 2nd Floor Test Locations

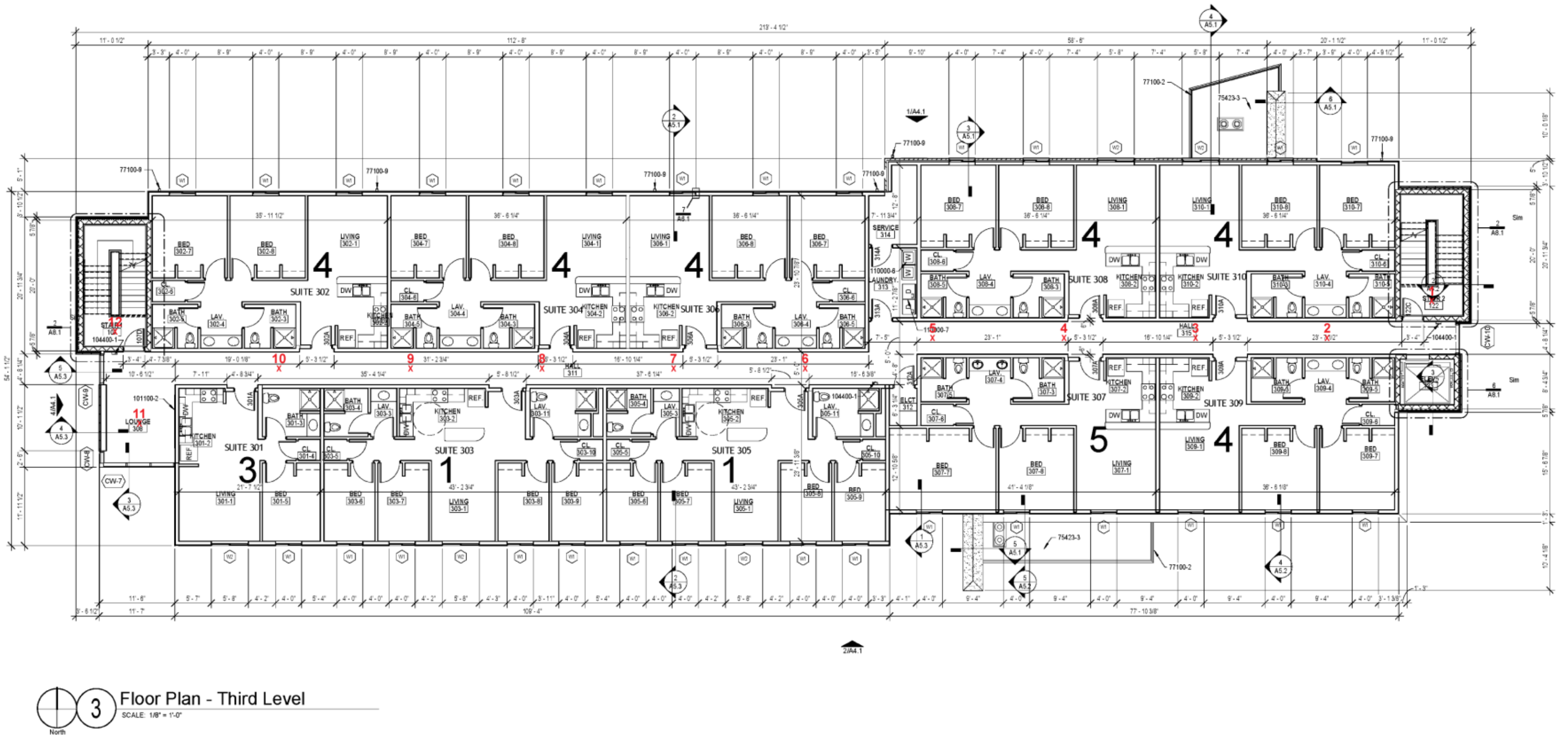

Figure A.3– 3rd Floor Test Locations

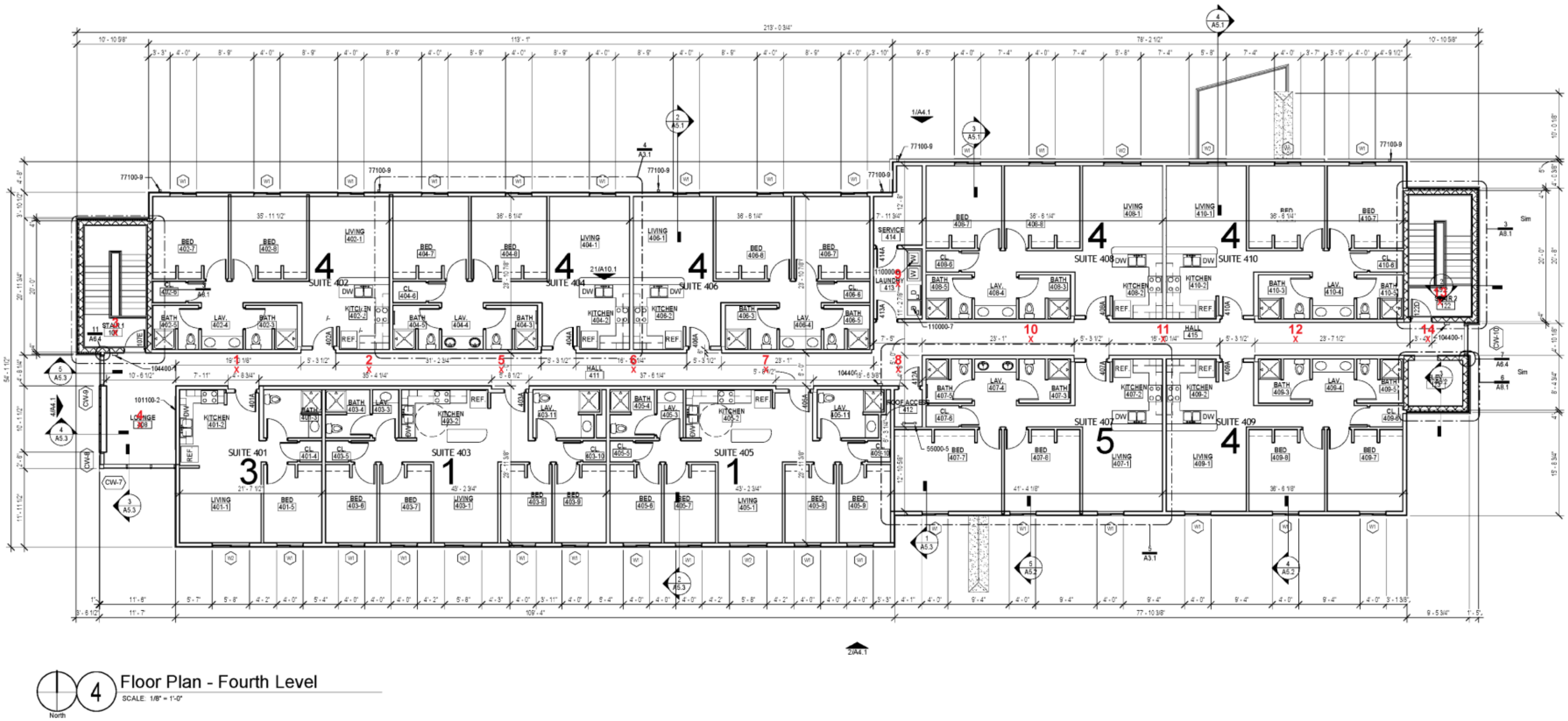

Figure A.4– 4th Floor Test Locations